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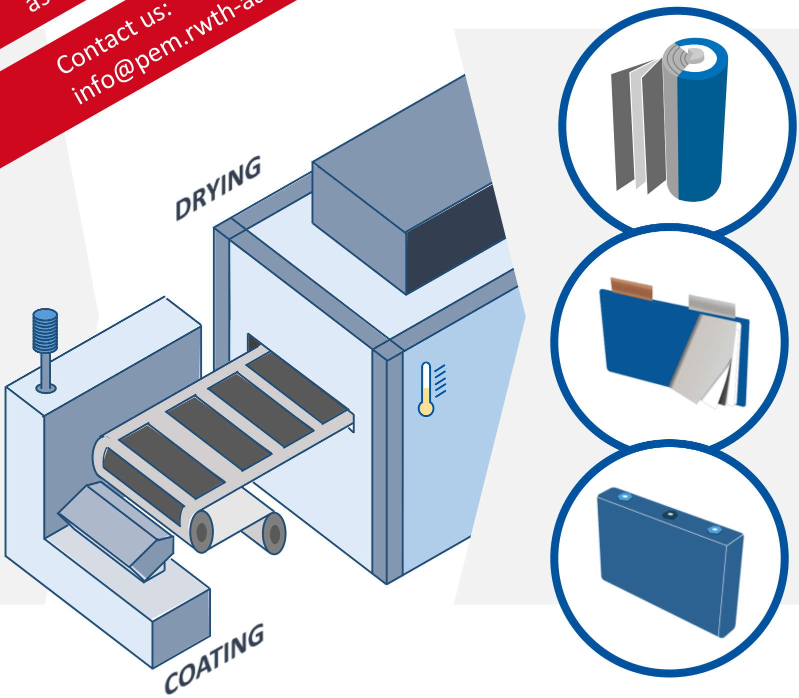


LITHIUM-ION BATTERY CELL PRODUCTION PROCESS

PEM | RWTH AACHEN UNIVERSITY

VDMA
Battery Production

PEM of RWTH Aachen University has been active for many years in the area of lithium-ion battery production. The range of activities covers automotive as well as stationary applications. Many national and international industry projects with companies throughout the entire value chain as well as leading positions in notable research projects allow PEM to offer a broad expertise.

The German Mechanical Engineering Industry Association (VDMA) represents more than 3200 companies in the mechanical engineering sector, which is dominated by SMEs. The battery production department focuses on battery production technology. Member companies supply machines, plants, machine components, tools and services in the entire process chain of battery production: From raw material preparation, electrode production and cell assembly to module and pack production.

PEM
Chair of Production Engineering of E-Mobility Components
Campus Boulevard 30
52074 Aachen

www.pem.rwth-aachen.de

VDMA
Battery Production
Lyoner Straße 18
60528 Frankfurt am Main

www.vdma.org

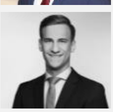
Authors

PEM der RWTH Aachen

Dr.-Ing. Dipl.-Wirt.-Ing. Heiner Hans Heimes
Chief Engineer
Head of E-Mobility Laboratory
H.Heimes@pem.rwth-aachen.de

Prof. Dr.-Ing. Achim Kampker

Christoph Lienemann, M. Sc. M. Sc.
Team Leader Battery Production
C.Lienemann@pem.rwth-aachen.de



Marc Locke, M. Sc.
Battery Production
M.Locke@pem.rwth-aachen.de

Christian Offermanns, M. Sc.
Battery Production
C.Offermanns@pem.rwth-aachen.de

VDMA

Dr. Sarah Michaelis
Battery Production, Division Manager
Sarah.Michaelis@vdma.org

Ehsan Rahimzei
Battery Production, Project Manager
Ehsan.Rahimzei@vdma.org

Any questions?

Contact us!

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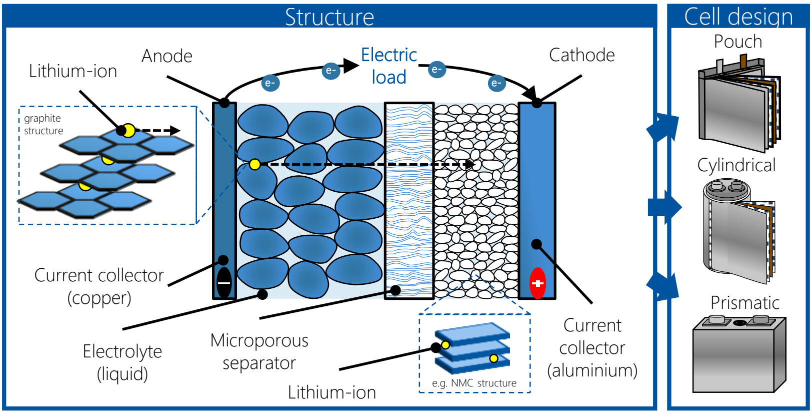
Operating Principle

of a lithium-ion battery cell



Electrode manufacturing → Cell assembly → Cell finishing

- The production of the lithium-ion battery cell consists of three main process steps: electrode manufacturing, cell assembly and cell finishing.
- Electrode production and cell finishing are largely independent of the cell type, while within cell assembly a distinction must be made between pouch cells, cylindrical cells and prismatic cells.
- Regardless of the cell type, the smallest unit of any lithium ion cell consists of two electrodes and a separator, which separates the electrodes from each other. The ion-conductive electrolyte fills the pores of the electrodes and the remaining space inside the cell.

Technological Development

of a lithium-ion battery cell

Product innovation (excerpt)

- Permutations
  - NMC 811 (high nickel batteries)
  - Silicon Graphite Anodes (Si/C)
- Carrier materials and electrolytes
  - Metal meshes
  - Solid electrolytes
- Fourth generation technology
  - Large format cells
  - Lithium metal anodes

Process innovation (excerpt)

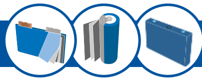
- Electrode manufacturing
  - Extrusion
  - Laser drying
- Cell assembly
  - Laser cutting
  - Lamination of the separator
- Cell finishing
  - Integrated product carrier concepts
  - Energy recovery

- Recent technology developments will reduce the material and manufacturing costs of lithium-ion battery cells and further enhance their performance characteristics.

*Following: Vuorilehto, K.; Materialien und Funktion, In Korthauer, R. (ed.): Handbuch Lithium-Ionen-Batterien, Springer, Berlin, 2013, S.22

Mixing

Electrode manufacturing

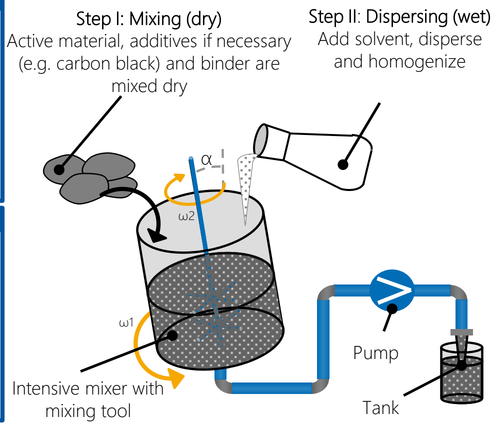


Anode formulation*

Active material: Graphite (90 wt.%))
Conductive carbon black: Nano microscopic carbon, e.g. Super P® (5 wt.%)
Solvent: Deionized water
Binder: CMC (3 wt.%)
Additive: SBR (2 wt.%)

Cathode formulation*

Active material: $Li(NiMnCo)O_2$ (90 wt.%)
Carbon black: Nano microscopic carbon, e.g. Super P® (5 wt.%)
Solvent: N-Methyl-2-Pyrrolidone (NMP)
Binder: PVDF (5 wt.%)



Cell assembly | Cell finishing

Production process

- With the help of a rotating tool at least two separated raw materials are combined to form a so-called slurry.
- The production of slurry requires not only active materials but also conductive additives, solvents and binders.
- A distinction is made between mixing (dry mixing) and dispersing (wet mixing). In addition, the process can be performed under vacuum to avoid gas inclusions.
- The choice of the mixing and dispersing sequence must be adapted to the electrode design to be produced.

Additional information

- The onward transport to the process step "coating" takes place through pipework or in sealed storage tanks.
- Active materials, conductive additives, solvents and binders are purchased components for many cell manufacturers.

Process parameters & requirements

- α: 0°- 10°
- Mixing time: 30 min to 5 h
- Temperature: 20°C to 40°C
- Atmosphere: protective gas, vacuum, room atmosphere (clean room)
- Different mixers for anode and cathode to avoid cross-contamination

Technology alternatives [excerpt]

- Various mixing technologies and mixing tools: Intensive mixers, planetary mixers, dispersers, etc.
- Continuous mixing: The active materials and additives are mixed in a continuous process (extruder). The slurry is then stored or transported directly via pipelines to the coating process.

Quality influences [excerpt]

- Mixing and dispersing sequence
- Filter materials and filter systems
- Shear forces
- Mixing temperature

Quality features [excerpt]

- Homogeneity of the slurry
- Particle size
- Purity (amount of foreign objects)
- Viscosity

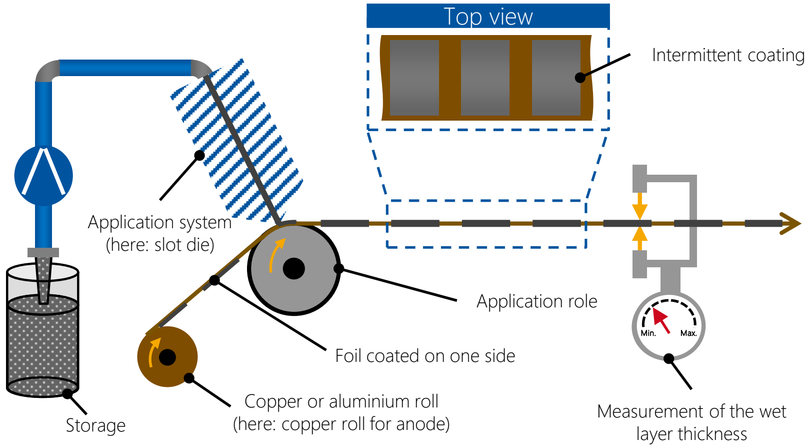
Production costs* [excerpt]

Invest for machinery and equipment: € 18-34 million
(Mixing)

* Study by the PEM of RWTH Aachen University: approx. 45,000,000 pouch cells/a, cell capacity: 25 Ah, 4 GWh/a

Coating

Electrode manufacturing



Production process

- The foil is coated with the slurry using an application tool (e.g. slot die, doctor blade, anilox roller).
- The foil is coated either continuously or intermittently in the coating direction.
- Generally, the top and bottom sides of the foil are coated sequentially.
- The coated foil is continuously transferred to the dryer. After the first drying process, the foil coated on one side is fed back to the coating system by a manual transport process.
- Afterwards, the second side is coated according to the process described.

Additional information

- Aluminium foil (rolled) and copper foil (rolled or electrolytically produced) are usually purchased components for the cell manufacturer.
- The film thicknesses (anode - copper foil and cathode - aluminium foil) vary between 5 µm and 25 µm depending on the cell design.

Process parameters & requirements

- Dry film thickness on one side: 50 µm - 100 µm (anode), 40 µm - 80 µm (cathode)
- Coating speed: 35 m/min - 80 m/min
- Coating width: up to 1500 mm
- Coating accuracy dry (± 2 g/m²)

Technology alternatives [excerpt]

- Various application tools (e.g. slot die, comma bar, anilox roller)
- Simultaneous coating: The top and bottom sides of the foil are coated simultaneously by two opposite application tools.
- Dry coating: With dry coating, the active material is applied to the carrier foil in powder form without solvent.

Quality influences [excerpt]

- Quality monitoring (surface quality, layer thickness)
- Application tool
- Precision of the slurry pump

Quality features [excerpt]

- Coating thickness accuracy (homogeneity in and across the coating direction)
- Surface quality (blowholes, particles)
- Adhesion between coating and substrate

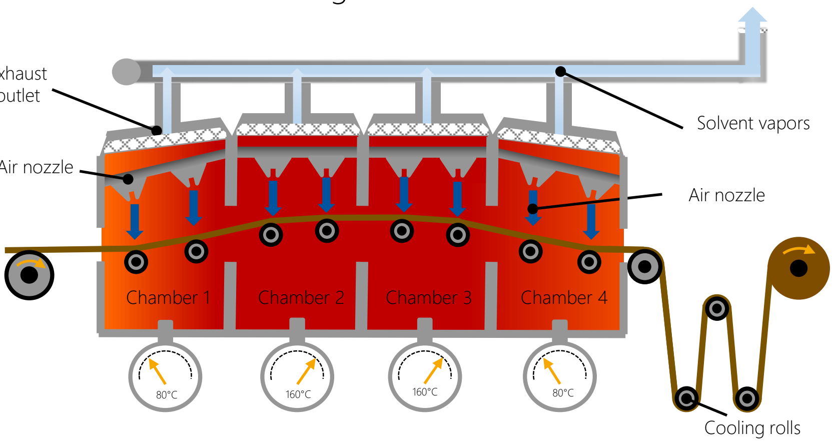
Production costs* [excerpt]

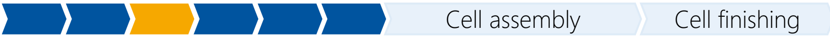
Invest for machinery and equipment: 16-35 Mio. €
(Coating & Drying)

* Study by the PEM of RWTH Aachen University: approx. 45,000,000 pouch cells/a, cell capacity: 25 Ah, 4 GWh/a

Drying

Electrode manufacturing





Production process

- After coating, the applied active material is dried in a continuous process.
- The solvent is removed from the material by heat supply.
- The highly flammable solvent contained in the cathode coating is recovered or used for thermal recycling.
- The transport of the foil is realized either by roller systems or by floatation air streams. For a simultaneous, double-sided coating, floatation dryer must be used.
- The dryer is divided into different temperature zones to realize an individual temperature profile. This is normally realized by a chamber system.
- After passing through the dryer, the foil is cooled down to room temperature and, depending on the type of system, rewound (conventional) or directly coated on the second side (tandem coating).

Additional information

- The throughput speed during coating defines the length of the dryer section.

Process parameters & requirements

- Drying speed: 35 m/min - 80 m/min
- Length of dryer: up to 100 m
- Temperature profile in the dryer zones: 50°C - 160°C
- Solvent recovery (hazardous substances); thermal afterburning
- Suitable foil pre-tensioning is important to avoid film tears

Technology alternatives [excerpt]

- Infrared drying: The conventional convection dryers can be supplemented by infrared heating and thus made more efficient.
- Laser drying: By using a laser, the dryer length can be shortened and energy costs can be saved. This technology is still in the development phase.

Quality influences [excerpt]

- Determination of the process parameters depending on the electrode design
- Choice of foil pretension
- Temperature profile

Quality features [excerpt]

- Adhesion between coating and substrate
- Residual humidity
- Surface finish (cracks, inclusions, etc.)

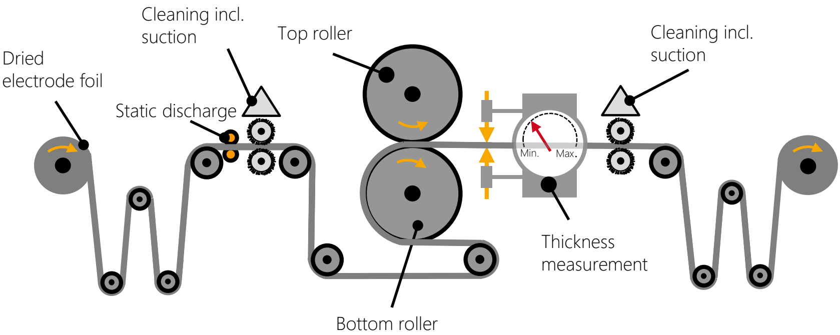
Production costs* [excerpt]

Invest for machinery and equipment: 16-35 Mio. €
(Coating & Drying)

* Study by the PEM of RWTH Aachen University: approx. 45,000,000 pouch cells/a, cell capacity: 25 Ah, 4 GWh/a

Calendering

Electrode manufacturing



Cell assembly | Cell finishing

Production process

- During calendering, the copper or aluminium foil coated on both sides is compressed by a rotating pair of rollers.
- The electrode foil is first statically discharged and cleaned by brushes or air flow.
- The material is compacted by the top and bottom rollers.
- The pair of rollers generates a precisely defined line pressure.
- After calendering, the electrode foil is cleaned and rolled up again (roll-to-roll process).

Additional information

- Line pressure defines the porosity of the coated material which influences the subsequent wetting properties of the electrodes and the energy density of the cell.
- If the line pressure is set too high, a squeezing process occurs and leads to stress cracks.
- The cleanliness of the rollers is crucial for preventing foreign particles from penetrating the substrate material.

Process parameters & requirements

- Maintaining a constant line pressure of up to 2,500 N/mm
- Calendering speed: 60 m/min - 100 m/min
- Porosity is reduced from 50% (after drying) by calendering to 20% to 40% (defined by the gap width).
- Preheating sections and roller temperature control is possible (approx. 50°C - 250°C)

Technology alternatives [excerpt]

- Hot rollers: Depending on the system concept the top and bottom rollers can be heated. In this way, the ductility of the active material can be brought to a defined value. Usually water or oil is used as the heating medium.

Quality influences [excerpt]

- Line pressure
- Roller material and diameter
- Surface accuracy and concentricity of the rollers
- Roller temperature

Quality features [excerpt]

- Defined porosity
- Surface texture
- Adhesion between coating and substrate

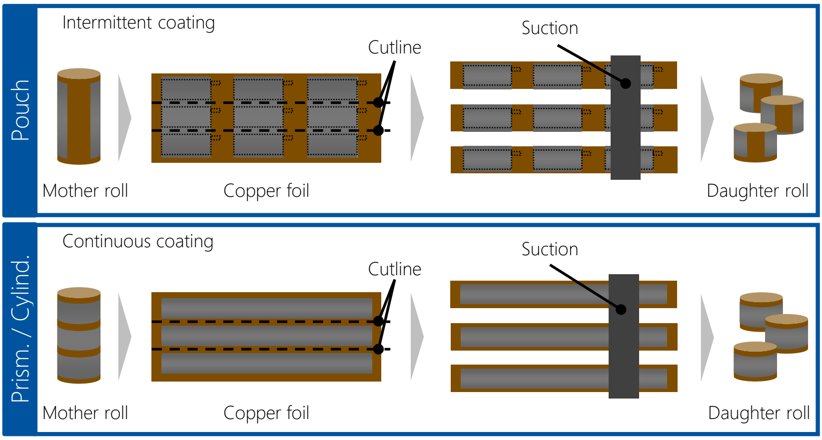
Production costs* [excerpt]

Invest for machinery and equipment: € 5-10 million
(Calendering)

* Study by the PEM of RWTH Aachen University: approx. 45,000,000 pouch cells/a, cell capacity: 25 Ah, 4 GWh/a

Slitting

Electrode manufacturing



cell assembly | cell finishing

Production process

- The calendered mother rolls are usually fed to the slitting station by a manual transport process.
- Slitting is a separation process in which a wide electrode coil (mother roll) is divided into several smaller electrode coils (daughter rolls).
- Generally, rolling knives are used for this purpose.
- The individual daughter rolls are cleaned and rewound after the cutting process (roll-to-roll process).

Additional information

- The electrode coils are cleaned by suction and/or brushes.
- The cut quality of the electrode edges and the cleanliness of the coils are considered as the main quality criteria.
- The cutting width of the daughter rolls can vary depending on the cell design and lies between 60 mm and 300 mm in many applications.

Process parameters & requirements

- Cutting speed (mechanical): 80 m/min - 150 m/min
- Suction for the separated edge strips
- Cutting width tolerance: ±150 µm up to ±250 µm
- Burr-free cutting

Technology alternatives [excerpt]

- Laser slitting: A laser can also be used for the cutting process. This technology offers greater flexibility. However, the risk of damage to the active material or contamination by dust increases when laser slitting is used.

Quality influences [excerpt]

- Finishing of cutting blades
- Process parameters as a function of coating thickness
- Extraction of dust / cutting waste

Quality features [excerpt]

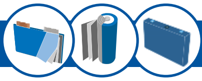
- Edge geometry (cutting burr)
- Thermal (temperature-affected zone) and mechanical stress
- Particle contamination during the cutting process

Production costs* [excerpt]

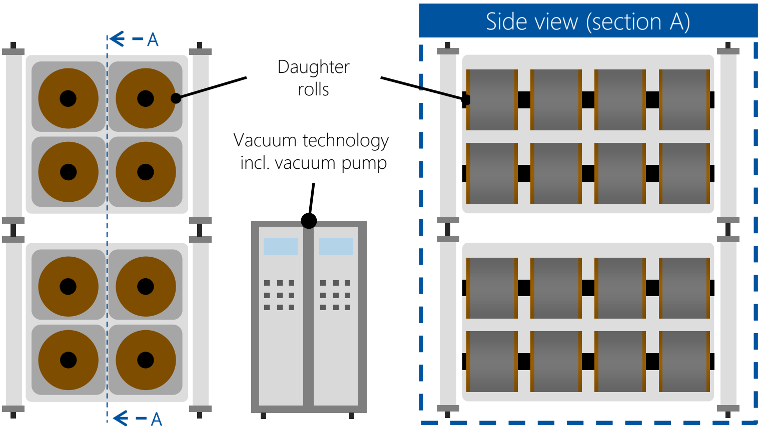
Invest for machinery and equipment: € 3-8 million
(Slitting)

* Study by the PEM of RWTH Aachen University: approx. 45,000,000 pouch cells/a, cell capacity: 25 Ah, 4 GWh/a

Vacuum Drying



Electrode manufacturing



Cell assembly | Cell finishing

Production process

- The coated daughter rolls are pushed onto a special goods carrier.
- The coils are then stored in a vacuum oven.
- The drying time is approx. 12 h to 30 h. During the drying process, residual moisture and solvents are removed from the coils.
- The reduction of residual moisture is achieved by evaporation at low temperatures as a result of a low total pressure.
- After vacuum drying has been completed, the coils are transferred directly to the dry room or dry packed under vacuum.

Additional information

- The vacuum ovens are often used as air locks into the dry room (for daughter rolls).
- In addition, it is possible to operate the vacuum ovens with inert gas in order to prevent corrosion.

Process parameters & requirements

- Working pressure: 0.07 mbar < p < 1000 mbar
- Drying time: 12 h - 30 h per batch
- Drying temperature: 60°C - 150°C
- Inert gas supply

Technology alternatives [excerpt]

- Continuous dryers: In contrast to the chamber concept, there are also continuous drying processes in which the daughter rolls are transported through a long drying facility in a wound or unwound state.
- Infrared dryer: Both technologies can be supplemented by infrared heating.

Quality influences [excerpt]

- Constant heat supply and stable vacuum
- Longer resting times only possible in the dry room
- Inert gas supply against corrosion

Quality features [excerpt]

- Surface condition (cracks, etc.)
- Residual moisture content (no residual moisture desired)

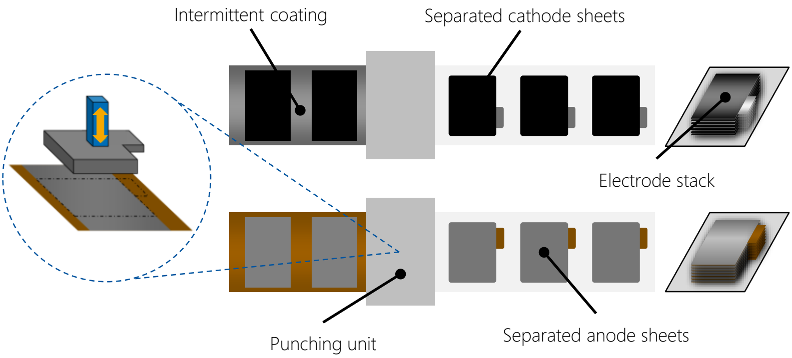
Production costs* [excerpt]

Invest for machinery and equipment: € 6-12 million
(vacuum drying)

* Study by the PEM of RWTH Aachen University: approx. 45,000,000 pouch cells/a, cell capacity: 25 Ah, 4 GWh/a

Separation

Cell assembly



Electrode manufacturing → Cell finishing

Production process

- Separation is necessary for the production of the pouch cell and describes the separation of anode, cathode and separator sheets from the roll material (daughter rolls).
- The dried daughter rolls are unwound and fed to the separation tool.
- The cutting process is usually carried out with a shear cut (punching tool) in a continuous process.
- Depending on the system concept, the individual sheets (coated on both sides) are stored in a magazine or transferred directly to the next process step.

Additional information

- The blank edge of the sheets are later used as the welding area for the cell tabs.
- The waste as well as the cutting dusts are extracted and transported away in the process.

Process parameters & requirements

- Separation time punching: approx. 0.2 s/sheet
- Tolerance requirements: approx. ±200 µm width and length tolerance for the sheets
- Punching tool: Very good cutting edge quality (depending on wear resistance)

Technology alternatives [excerpt]

- Laser ablation: A guided laser beam allows the active material to be ablated again at defined points, thus exposing the carrier foil. This technology offers a high flexibility with regard to the positioning of the cell tabs.
- Laser cutting: Instead of a conventional punching tool, the electrodes can also be cut out by a laser.

Quality influences [excerpt]

- Heat-affected zone and suction of evaporated material during laser cutting
- Finishing of tools
- Cutting/punching speed

Quality features [excerpt]

- Cutting edge geometry (e.g. smearing of the active material over the cutting edges)
- Thermal and mechanical stress during the cutting process

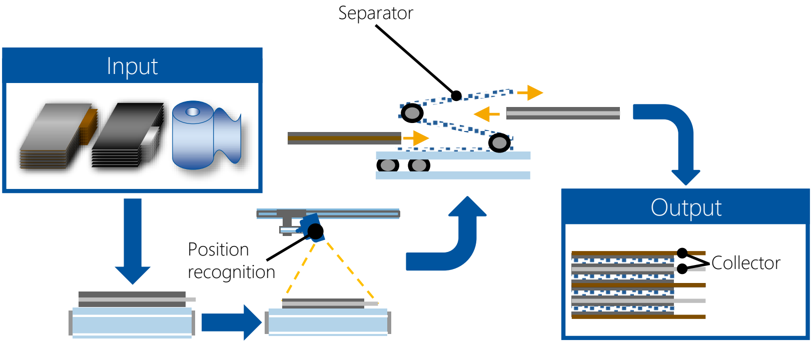
Production costs* [excerpt]

Invest for machinery and equipment: € 5-10 million
(Separating pouch)

* Study by the PEM of RWTH Aachen University: approx. 45,000,000 pouch cells/a, cell capacity: 25 Ah, 4 GWh/a

Stacking

Cell assembly



Electrode manufacturing → Cell finishing

Production process

- During the stacking process the separated electrode sheets are stacked in a repeating cycle of anode, separator, cathode, separator, etc.
- A wide variety of stacking technologies exist, which are usually patented by specific manufacturers.
- A classic variant of stacking is the so-called Z-folding.
- The anode and cathode sheets are inserted alternately from the left and right into the z-shaped folded separator. The separator is used in the form of an endless tape and is cut off after the stacking process.
- The cell stack is finally fixed with adhesive tape.

Additional information

- The exact positioning of the individual sheets is considered as the central quality criterion.
- The sheets are usually transported and positioned by vacuum grippers.
- Depending on the cell specification, a cell stack can consist of up to 120 individual layers.

Process parameters & requirements

- Z-folding: Individual anode and cathode sheets are placed laterally in the Z-folded separator web
- Single-sheet stacking: Separator is available as a sheet for stack formation
- Stacking accuracy: ± 200 µm - 300 µm
- Z-folding and single-sheet stacking : cycle times of 1 s/sheet

Technology alternatives [excerpt]

- Lamination process: The individual electrode and separator sheets are laminated onto each other in a continuous process and are then usually pressed together by a heat press.
- Pocket Stacking: The cathode sheets are placed in a separator pocket. Afterwards cathode and anode sheets are stacked alternately.

Quality influences [excerpt]

- Position detection and alignment of sheets of different sizes with a vacuum gripper
- Mechanical pre-tensioning of the separator

Quality features [excerpt]

- Positioning accuracy of the anode and cathode sheets
- Damage-free electrode surfaces and edges
- Avoidance of electrostatic charging

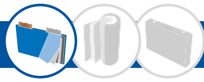
Production costs* [excerpt]

Invest for machinery and equipment: € 18-27 million
(Stacking pouch)

* Study by the PEM of RWTH Aachen University: approx. 45,000,000 pouch cells/a, cell capacity: 25 Ah, 4 GWh/a

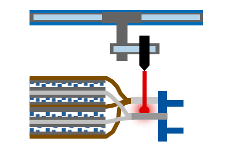
Packaging

Cell assembly

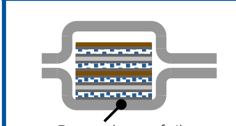


Deep drawing of the pouch foil

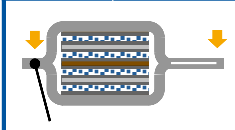
Welding of cell tabs



Insertion



Partial sealing of the pouch



Electrode manufacturing → → → → Cell finishing

Production process

- To package the pouch cell, the current collector foils (anode - copper and cathode - aluminium) are first contacted with the cell tabs using an ultrasonic or laser welding process.
- The cell stack is then positioned in the pouch foil. For this purpose, the pouch foil is deep-drawn in an earlier process step.
- The pouch cell is usually sealed gas-tight on three sides in an impulse or contact sealing process.
- One side of the cell (often the bottom of the cell) is not finally sealed in order to be able to fill the cell with electrolyte in the next process step.

Additional information

- The packaging materials are generally to be regarded as purchased parts.
- The deep drawing of the pouch foil is carried out either directly in the production line or in a separate process.

Process parameters & requirements

- Deep drawing: up to 6 mm
- Ultrasonic welding with approx. 15 kHz - 40 kHz
- Packaging material: aluminium composite film (polyamide/aluminium/polypropylene)
- Rule of thumb: "1 mm sealing seam width corresponds to approximately one year of cell lifetime".

Technology alternatives [excerpt]

- Book folding process: Instead of two individual pouch foils, a foil with two deep drawn cavities can also be used for insertion into the packaging. After the stack has been inserted, the foil is folded like a book and then sealed.

Quality influences [excerpt]

- Reduction of thermal stress during contacting and sealing process
- Seal seam width
- Sealing temperature and pressure

Quality features [excerpt]

- Low contact resistance as well as low mechanical and thermal stress during the welding process
- Fatigue strength and tightness of the sealing seams

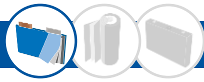
Production costs* [excerpt]

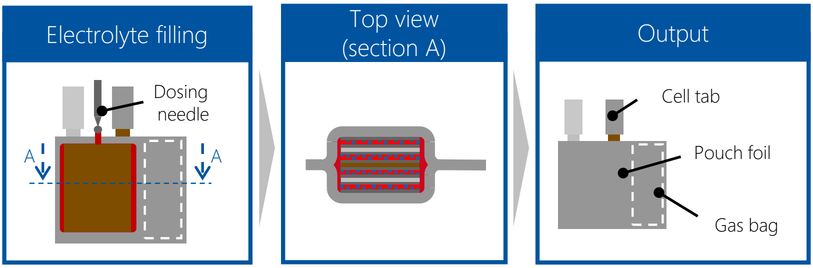
Invest for machinery and equipment: € 16-23 million
(Packaging pouch)

* Study by the PEM of RWTH Aachen University: approx. 45,000,000 pouch cells/a, cell capacity: 25 Ah, 4 GWh/a

Electrolyte Filling

Cell assembly





Production process

- After the packaging process the electrolyte is filled in.
- During electrolyte filling, a distinction must be made between the sub-processes "filling" and "wetting".
- The electrolyte is filled into the cell under vacuum (filling) with the help of a high-precision dosing needle.
- By applying a pressure profile to the cell (supply of inert gas and/or generation of a vacuum in alternating operation), the capillary effect in the cell is activated (wetting).
- Evacuation and partial filling are repeated several times depending on the manufacturer and cell type.
- Finally, the pouch foil is sealed under vacuum.

Additional information

- The electrolyte (e.g. LiPF6) is usually a purchased component and sets high requirements on the process environment (fire protection, extraction, etc.), due to its classification as a hazardous substance.

Process parameters & requirements

- Geometry of the dosing needle
- Working pressure: approx. 0.01 mbar
- Consistent, continuous or cyclic filling to ensure homogeneous electrolyte distribution
- Very dry environment necessary
- Gravimetric control of the electrolyte quantity

Technology alternatives [excerpt]

- No alternatives in series production.

Quality influences [excerpt]

- Dosing method (e.g. dosing pump)
- Geometry and closing mechanism of the dosing needle
- Electrolyte transport system (piping, etc.)

Quality features [excerpt]

- Dosing and distribution accuracy of the electrolyte in the cell
- No electrolyte residues in the sealing seam
- Tightness of the sealed cell

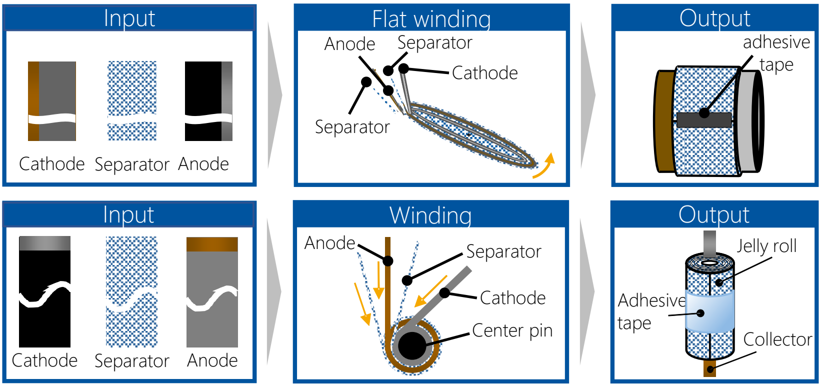
Production costs* [excerpt]

Invest for machinery and equipment: € 6-12 million
(Electrolyte filling pouch)

* Study by the PEM of RWTH Aachen University: approx. 45,000,000 pouch cells/a, cell capacity: 25 Ah, 4 GWh/a

Winding

Cell assembly



Electrode manufacturing → → → → Cell finishing

Production process

- Winding is required for the production of prismatic cells and cylindrical cells and takes place after vacuum drying of the daughter rolls.
- The electrode foils and two separator foils are wound around a winding mandrel (prismatic cell) or a centre pin (cylindrical cell). The foil sequence is similar to the stacking process.
- The wound product is called jelly roll.
- The positioning of the individual foils of the Jelly Roll is finally secured by an adhesive strip.

Additional information

- The exact positioning and alignment of the electrode foils and separator foils is regarded as the central quality criterion.
- The process times for the winding process are significantly shorter than for the stacking process described above.

Process parameters & requirements

- Machine throughput: up to 30 cells/minute (cylindrical cell)
- Integration of the tab welding process in the winding machine for cylindrical cells
- Machine throughput up to 6 cells/minute (prismatic cell)

Technology alternatives [excerpt]

- No alternatives in series production.

Quality influences [excerpt]

- Winding speed
- Web tension
- Web edge control
- Avoidance of electrostatic charging

Quality features [excerpt]

- Positioning accuracy of anode and cathode foils
- Damage-free electrode surfaces and edges

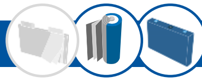
Production costs* [excerpt]

Invest for machinery and equipment: € 15-35 million
(Winding)

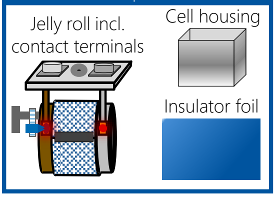
* Study by the PEM of RWTH Aachen University: 225,000,000 cylindrical cells/a, cell capacity: 4.8 Ah, 4 GWh/a

Packaging

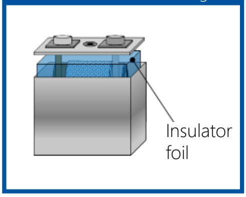
Cell assembly



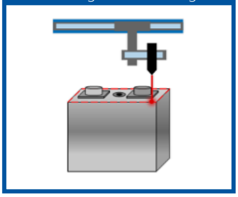
Input



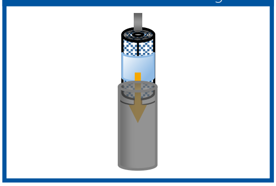
Insertion into the housing



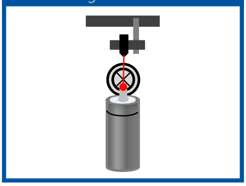
Welding of the housing



Insertion into the housing



Welding of the terminals



Electrode manufacturing → → → → Cell finishing

Production process

- In contrast to the cell stack in the pouch cell, the jelly roll is inserted into a robust metal housing.
- In the prismatic cell, the edges of the jelly roll are compressed, fixed and ultrasonically welded to the contact terminals attached to the lid of the battery.
- An insulation foil protects the jelly roll during insertion into the prismatic housing.
- The housing is usually sealed by a laser welding process.
- The first step in the cylindrical cell process is to insert a bottom insulator and the jelly roll into the cylindrical housing.
- Subsequently, the current collector of the anode is usually welded to the bottom of the housing and the current collector of the cathode is welded to the lid.
- Finally, an insulation ring is inserted between the jelly roll and the lid.

Additional information

- The cell housing and the insulation materials are generally to be regarded as purchased parts.

Process parameters & requirements

- Frequency of ultrasonic welding: approx. 15 kHz - 40 kHz
- Flexible beam guidance and shaping during laser welding of the lid of the prismatic cell
- Connection between anode and housing: resistance welding
  Connection between cathode and cell lid: laser welding

Technology alternatives [excerpt]

- No alternatives in series production.

Quality influences [excerpt]

- Reduction of thermal stress during welding processes
- Purity of the metallic housing
- Handling of the jelly roll

Quality features [excerpt]

- Low contact resistance as well as low mechanical and thermal stress during the welding process
- Insulation against the metallic housing

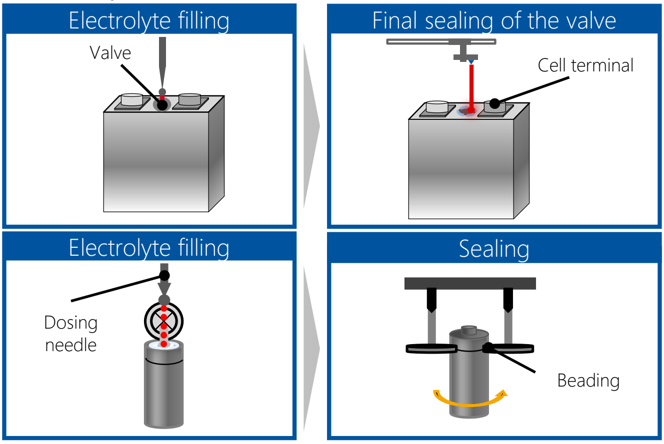
Production costs* [excerpt]

Invest for machinery and equipment: 10-20 million €
(Packaging prism. / cylindr.)

* Study by the PEM of RWTH Aachen University: 225,000,000 cylindrical cells/a, cell capacity: 4.8 Ah, 4 GWh/a

Electrolyte Filling

Cell assembly



Electrode manufacturing | Cell finishing

Production process

- The electrolyte filling takes place after the jelly roll has been inserted into the housing.
- During electrolyte filling, a distinction must be made between the sub-processes "filling" and "wetting".
- The electrolyte is filled into the cell under vacuum (filling) with the help of a high-precision dosing needle.
- By applying a pressure profile to the cell (supply of inert gas and/or generation of a vacuum in alternating operation), the capillary effect in the cell is activated (wetting).
- Evacuation and partial filling are repeated several times depending on the manufacturer and cell type.
- Afterwards the cells are sealed (e.g. crimping, beading, welding).

Additional information

- The electrolyte (e.g. $LiPF_6$) is usually a purchased component and sets high requirements on the process environment (fire protection, extraction, etc.), due to its classification as a hazardous substance.

Process parameters & requirements

- Working pressure: approx. 0.01 mbar
- Consistent, continuous or cyclic filling to ensure homogeneous electrolyte distribution
- Very dry environment necessary
- Gravimetric control of the electrolyte quantity

Technology alternatives [excerpt]

- No alternatives in series production.

Quality influences [excerpt]

- Dosing method (e.g. dosing pump)
- Geometry and closing mechanism of the dosing needle
- Electrolyte transport system

Quality features [excerpt]

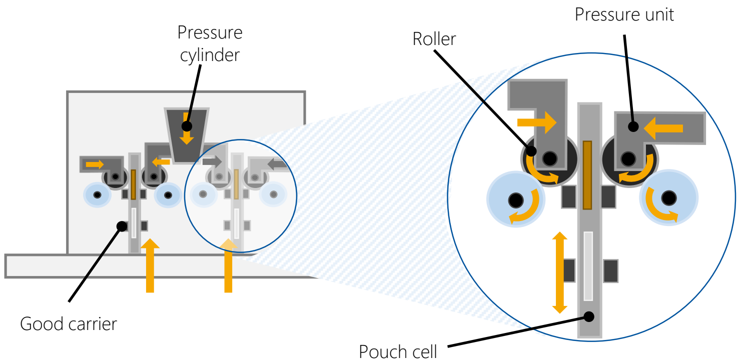
- Dosing and distribution accuracy of the electrolyte in the cell
- Tightness of the sealed cell
- electrolyte quantity

Production costs* [excerpt]

Invest for machinery and equipment: 12-18 million €
(Electrolyte filling prism. / cylindr.)

* Study by the PEM of RWTH Aachen University: 225,000,000 cylindrical cells/a, cell capacity: 4.8 Ah, 4 GWh/a

Roll Pressing
Cell finishing



Electrode manufacturing | Cell assembly

Production process

- After electrolyte filling, an optional roll pressing process can take place for the pouch cell.
- The lithium-ion pouch cell is clamped in a special good carrier with the help of a gripper.
- A servo motor guides the cell through two rollers that apply a defined pressure.
- The rollers are cleaned in the meantime by cleaning rollers.
- Roll pressing ensures optimum distribution and absorption of the electrolyte under defined pressure.
- This step serves as preparation for the subsequent formation because electrochemically inactive areas are avoided by the pressurisation.

Additional information

- Roll pressing ensures that the maximum capacity of the cells is achieved and the rejection rate is reduced.

Process parameters & requirements

- Defined pressure
- Homogeneous distribution of pressure over the entire cell surface
- Process times between 2 and 5 seconds per cell
- Ensuring the ideal coverage of the individual electrode sheets

Technology alternatives [excerpt]

- Depending on the manufacturer, a vibrating table is used for prismatic and cylindrical cells to ensure optimum electrolyte wetting.

Quality influences [excerpt]

- Pressure distribution
- Roller geometry
- Process control (number of passes, etc.)

Quality features [excerpt]

- Optimum formation of the SEI layer during the subsequent formation process
- Electrolyte distribution within the cell
- Capacity of the cell after formation

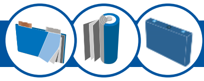
Production costs* [excerpt]

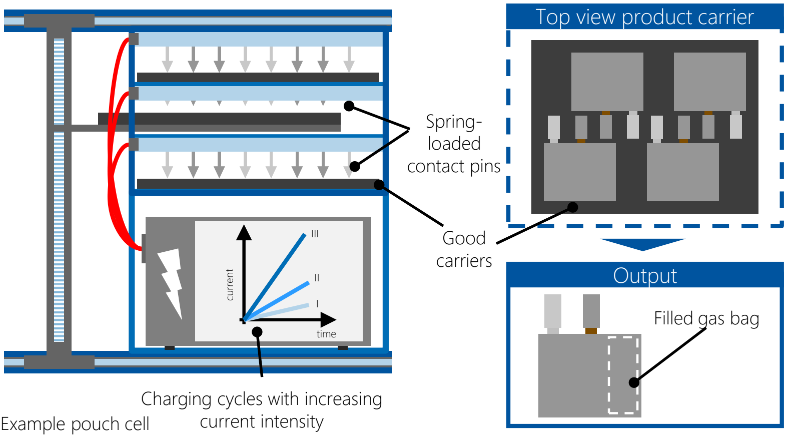
Invest for machinery and equipment: € 4-8 million
(Roll pressing pouch)

* Study by the PEM of RWTH Aachen University: approx. 45,000,000 pouch cells/a, cell capacity: 25 Ah, 4 GWh/a

Formation

Cell finishing





*Example pouch cell

Electrode manufacturing | Cell assembly

Production process

- The formation describes the first charging and discharging processes of the battery cell.
- For formation, the cells are put in special good carriers in formation racks and contacted by spring-loaded contact pins.
- The cells are then charged or discharged according to precisely defined current and voltage curves.
- During formation, lithium ions are embedded in the crystal structure of the graphite on the anode side. Here the Solid Electrolyte Interface (SEI) is formed, which creates a interface layer between the electrolyte and the electrode.

Additional information

- The parameters during formation vary depending on the cell manufacturer and have a high impact on cell performance. They depend on the cell concept and chemistry and represent the core knowledge of a cell manufacturer.
- In some cases, pouch cells in particular are pressurised during formation by special good carriers.

Process parameters & requirements

- First charge: approx. 0.1 C - 0.5 C; State of Charge (SOC) approx. 20 % - 80 %
- Successive increase in C-rates with each charging and discharging cycle
- Duration of formation process: up to 24 h
- Low contact resistances at the spring-loaded contact pins

Technology alternatives [excerpt]

- There are different procedures for the formation depending on the cell manufacturer and cell chemistry.

Quality influences [excerpt]

- Orientation of the cells
- Contact method
- Process temperature
- Pressurisation, especially of pouch cells

Quality features [excerpt]

- Formation of the SEI layer
- Stability of the SEI layer
- Internal resistance of the cell

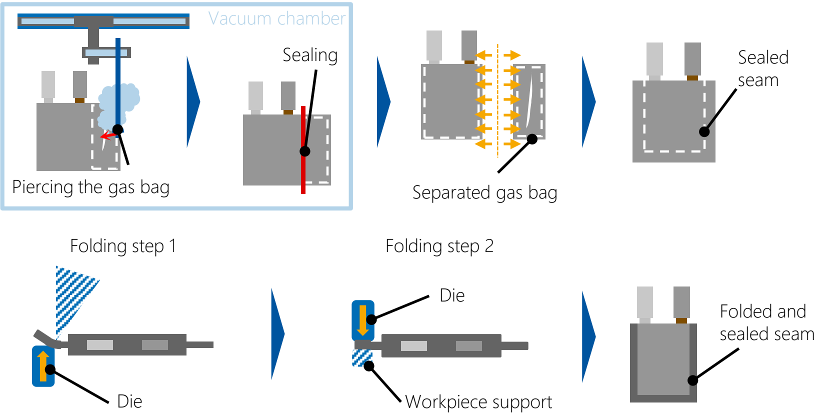
Production costs* [excerpt]

Invest for machines and plants: 70-90 Mio. €
(Formation)

* Study by the PEM of RWTH Aachen University: approx. 45,000,000 pouch cells/a, cell capacity: 25 Ah, 4 GWh/a

Degassing

Cell finishing



Electrode manufacturing | Cell assembly

Production process

- With many pouch cells (especially with larger cells) there is a strong evolution of gas during the first charging process.
- Pressurised good carriers are pressing this gas out of the cell into a dead space (also called a gas bag).
- During degassing, the gas bag is pierced in a vacuum chamber and the escaping gases are sucked off. The cell is then finally sealed under vacuum.
- The gas bag is separated and disposed as hazardous waste.
- Final folding and, if necessary, gluing of the seal edges to reduce the external dimensions of the pouch cell can be carried out as an option.

Additional information

- The extracted gases must be post-treated (e.g. RTO) before they are fed into the exhaust system, depending on occupational health and safety and environmental protection regulations.

Process parameters & requirements

- Folding and gluing of sealing seams to increase volumetric energy density
- Damage-free folding of the edges
- Seam widths of up to 1 cm
- Sealing against moisture and oxygen

Technology alternatives [excerpt]

- Particularly in the case of smaller cells with lower gas generation and depending on the manufacturer, the gas bag is not separated after degassing.

Quality influences [excerpt]

- Pressing of the cells for degassing
- Sealing and folding technology
- Suction of gases under vacuum and in a dry atmosphere

Quality features [excerpt]

- Residual gas inside the cell
- Damage-free cell handling (different characteristics of the gas bubbles)

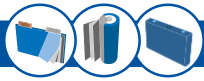
Production costs* [excerpt]

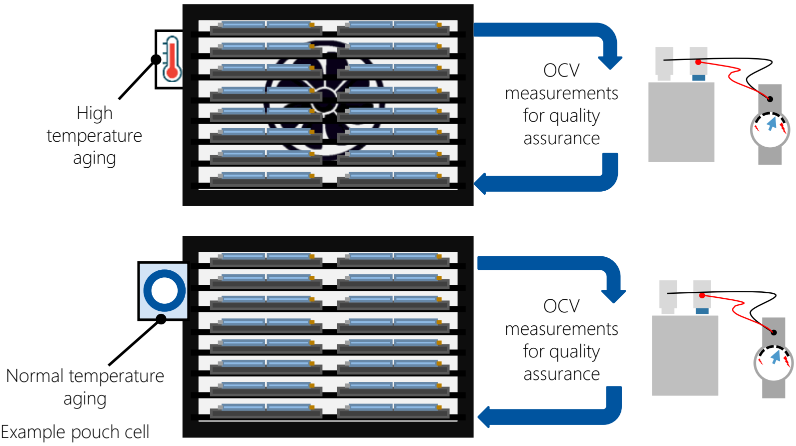
Invest for machinery and equipment: 10-15 million €.
(Degassing pouch)

* Study by the PEM of RWTH Aachen University: approx. 45,000,000 pouch cells/a, cell capacity: 25 Ah, 4 GWh/a

Aging

Cell finishing





*Example pouch cell

Electrode manufacturing | Cell assembly

Production process

- Aging represents the final step in cell production and is used for quality assurance.
- During aging, cell characteristics and cell performance are monitored by regularly measuring the open circuit voltage (OCV) of the cell over a period of up to three weeks.
- A distinction is made between high temperature (HT) and normal temperature (NT) aging. The cells usually first undergo HT aging and then NT aging.
- The cells are stored in so-called aging shelves and/or towers.
- No significant change in the cell properties over the entire period of time means that the cell is fully functional and can be delivered to the customer.

Additional information

- In contrast to formation, the pouch cells are no longer pressurised in this process step.
- The duration of the aging process depends strongly on the respective cell manufacturer and the cell chemistry used.

Process parameters & requirements

- State of charge of the cell at the beginning of aging: 80 % - 100 % SOC
- Aging time: up to 3 weeks
- Normal temperature approx. 22°C, high temperature approx. 30°C - 50°C

Technology alternatives [excerpt]

- There are different procedures for the sequence and duration of HT and NT aging depending on the cell manufacturer and cell chemistry.

Quality influences [excerpt]

- Orientation of cells
- Packing density of the cell good carriers
- Ambient temperature

Quality features [excerpt]

- Capacity
- Internal resistance
- Self-discharge rate

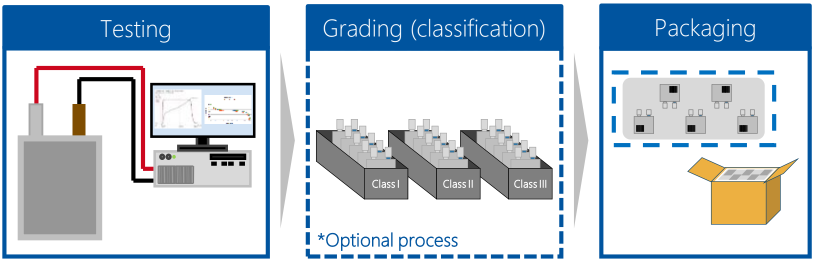
Production costs* [excerpt]

Invest for machinery and equipment: € 5-15 million
(Aging)

* Study by the PEM of RWTH Aachen University: approx. 45,000,000 pouch cells/a, cell capacity: 25 Ah, 4 GWh/a

EOL Testing

Cell finishing



*Example pouch cell

Electrode manufacturing | Cell assembly

Production process

- Before the cells leave the factory, they are tested in an EOL test rig.
- The cells are removed from the good carriers in the aging racks and fed to the testing station. Here they are discharged to the shipping state of charge (capacity measurement).
- Depending on the manufacturer, pulse tests, internal resistance measurements (DC), optical inspections, OCV tests and leakage tests are carried out.
- After testing, many cell manufacturers sort the cells according to their performance data (grading).
- Once the tests have been completed passed successfully, the cells can be packed and shipped.

Additional information

- For transport, the cells are usually provided with a plastic cover and stacked in a cardboard box.

Process parameters & requirements

- State of charge of the cell for shipping: 5 % - 20 % SOC
- Permissible loss rate: < 5 mV per week
- Increased loss rate: > 5mV per week may indicate e.g. cell-internal short circuits

Technology alternatives [excerpt]

- Different test sequences and durations exist depending on the cell manufacturer.

Quality influences [excerpt]

- Cell handling

quality characteristics

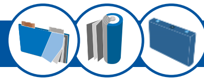
- Low self-discharge
- Low internal resistance
- Constant capacity

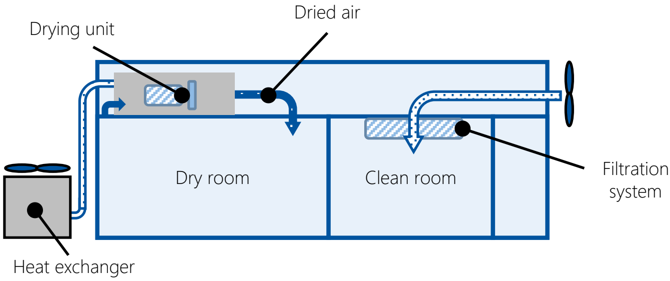
Production costs* [excerpt]

Invest for machinery and equipment: € 5-8 million
(EOL testing)

* Study by the PEM of RWTH Aachen University: approx. 45,000,000 pouch cells/a, cell capacity: 25 Ah, 4 GWh/a

Production Environment





	Clean room class	Dry room (dew point)	Temperature	Annotations
Mixing	ISO 8	/	22 ± 2 °C	The electrode manufacturing takes place under clean room conditions, since foreign particles in the coating cannot be removed in the later process by cleaning methods (e.g. suction).
Coating	ISO 7	semi-dry (5°C to -5°C)		
Drying				
Calendering	ISO 7 - ISO 8			
Slitting				
Vacuum drying		Dry (0°C to -30°C)		
Separation	min. ISO 7	Dry (-25°C to -35°C)	22 ± 2 °C	The cell assembly must be carried out under dry conditions, as water inside the cell leads to strong quality losses (service life) and to a safety risk (formation of hydrofluoric acid).
Stacking / Winding		Dry (-40°C to -50°C)		
Packaging				
EL filling		Extra dry (-50°C to -70°C)		
Formation	/	/	22 ± 3 °C	Cell finishing takes place in a normal environment. Since the cell is already sealed and degassing takes place in a vacuum chamber, there are fewer requirements for the particle environment and humidity.
Degassing				
HT aging			30 °C to 50 °C	
NT aging			22 ± 3 °C	
EOL testing				